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14. ABSTRACT The PIs pursued exploratory studies over the summer 2015 in preparation for an extensive novel interdisciplinary research program that aims to synergistically combine two powerful and very successful theories for non-linear stochastic dynamics of cooperative multi-component systems, namely critical dynamics and control theory. Specifically, our goal with our collaborators and students is to develop innovative protocols for: (1) steering multi-critical complex interacting dynamical systems toward certain desired universal scaling behavior; (2) externally controlling the strength of stochastic fluctuations and intrinsic noise in systems that are driven far					
15. SUBJECT TERMS Critical dynamics, control theory, complex systems, non-linear stochastic dynamics					
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a. REPORT UU	b. ABSTRACT UU	c. THIS PAGE UU			19b. TELEPHONE NUMBER 540-231-8998

Report Title

Final Report: Toward Control of Universal Scaling in Critical Dynamics

ABSTRACT

The PIs pursued exploratory studies over the summer 2015 in preparation for an extensive novel interdisciplinary research program that aims to synergistically combine two powerful and very successful theories for non-linear stochastic dynamics of cooperative multi-component systems, namely critical dynamics and control theory. Specifically, our goal with our collaborators and students is to develop innovative protocols for:

- (1) steering multi-critical complex interacting dynamical systems toward certain desired universal scaling behavior;
- (2) externally controlling the strength of stochastic fluctuations and intrinsic noise in systems that are driven far from thermal equilibrium and display generic scale invariance;
- (3) selectively targeting and stabilizing specific self-generated spatio-temporal patterns in strongly fluctuating reaction-diffusion systems and epidemic models.

The three PIs uniquely combine demonstrated scientific expertise and broad experience in (1) analytical as well as numerical investigations of critical dynamics in interacting many-body systems both near and far from thermal equilibrium, (2) universal short-time scaling in non-equilibrium aging scaling regimes, and (3) control theory and experiment. Over the past year, and especially during the summer 2015, we have held weekly meetings to learn each other's scientific language, and to become familiar and updated in our respective research fields. This STIR award allowed us to identify frontline research objectives that will close the gap between the hitherto rarely linked fields of statistical physics and control theory.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received

Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received

Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Book

TOTAL:

Received Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Co-PI Michel Pleimling was elected Fellow of the American Physical Society (APS) in November 2015, upon nomination by its Topical Group of Nonlinear and Statistical Physics (GSPN).

Co-PI Dan Stilwell with a former postdoc won the 2015 Kalman best paper award for the Journal of Dynamics, Measurements, and Control.

Graduate Students

<u>NAME</u>	<u>PERCENT SUPPORTED</u>	<u>Discipline</u>
Ahmadreza Azizi	0.00	
Jacob Carroll	0.00	
Sheng Chen	0.00	
Shannon Serrao	0.00	
Harun Yetkin	0.00	
FTE Equivalent:	0.00	
Total Number:	5	

Names of Post Doctorates

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>	National Academy Member
Uwe C. Tauber	0.10	
Michel Pleimling	0.10	
Daniel J. Stilwell	0.10	
FTE Equivalent:	0.30	
Total Number:	3	

Names of Under Graduate students supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>	Discipline
Peter Morrissey	0.20	Physics
Nathan Rogers	0.10	Physics
FTE Equivalent:	0.30	
Total Number:	2	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:..... 0.00

Names of Personnel receiving masters degrees

<u>NAME</u>
Total Number:

Names of personnel receiving PHDs

<u>NAME</u>
Total Number:

Names of other research staff

NAME

PERCENT SUPPORTED

FTE Equivalent:

Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

We specifically focused on identifying the decisive problems and well-suited model systems for controlling critical dynamics, and also intensely discussed potential difficulties as well as possible avenues for their resolution. We believe we have now defined various tractable theoretical model systems that will allow the external control of universal dynamical scaling features through innovative protocols. It is anticipated that the strong, long-range correlations near critical points should facilitate the control of global properties through local perturbations, provided the dynamical limitations induced by critical slowing-down can be overcome. The emergence of novel concepts and innovative mathematical tools is expected. The PIs will explore a wide range of potential applications that span from materials science, e.g., magnetism and surface growth, to ecology, epidemiology, synthetic biology, and social system dynamics.

Our in-depth discussions and analysis have resulted in our writing and submitting the research proposal Control of Universal Scaling, Noise Strength, and Pattern Formation in Critical Dynamics in response to the Strategic Program Challenges call in the Mechanical Sciences Division issued by the U.S. Army Research Office. This proposal, which envisions a four-year interdisciplinary research program that will also involve a postdoctoral associated and several graduate students specifically addresses Section 1.3.3, Topic 4: Control and Creation of Critical Dynamics, c.f. <http://www.arl.army.mil/www/default.cfm?page=206>.

We are currently in the process of training several graduate students in the considerable mathematical and conceptual background required to actively pursue this set of projects:

- Mr. Ahmedreza Azizi (adviser Co-PI Pleimling) uses numerical simulations to study the relaxation properties of the voter model, a stochastic interacting particle system that displays different critical points depending on the values of the system parameters. The voter model is one of the most promising candidates exhibiting multi-critical dynamical scaling that is still simple enough to allow for a detailed study of our ideas. This model will provide a crucial test bed for the development of both powerful diagnostic tools, namely monitoring the universal short-time dynamical scaling properties, and the establishment of a new innovative technology of feedback control.
- Mr. Jacob Carroll (adviser PI Täuber) is familiarizing himself with the literature on neural networks, i.e., long-range spin glasses with dynamically reset couplings, subject to Hebbian learning algorithms. Our goal is to understand these intriguing systems' kinetic properties and dynamical evolution in detail, and to explore the effects of modified or disrupted training schemes on the ensuing kinetics and efficacy.
- Mr. Sheng Chen (adviser PI Täuber) performs extensive Monte Carlo simulations on dynamical critical properties and aging scaling following rapid environmental parameter changes at extinction thresholds or active-to-absorbing phase transitions. He is also investigating noise-induced pattern formation and evolutionary dynamics in ecological models for competing coexisting species, or parasitic infections in epidemiology.
- Mr. Shannon Serrao (adviser PI Täuber) has acquired considerable analytic skills and expertise in field-theoretic representations of stochastic particle dynamics and chemical reactions. He currently explores cyclic competition models in evolutionary game theory and population dynamics. His calculations specifically address the purported mapping of these systems to a complex Ginzburg-Landau equation, at least near a Hopf bifurcation.
- Mr. Harun Yetkin (adviser Co-PI Stilwell) has contributed to stochastic receding horizon control and various aspects of search theory for autonomous vehicles. He has begun to investigate the connections between stochastic control for high-dimensional systems and statistical physics in the context of the specific example systems that appear in our submitted research proposal.
- In addition, undergraduate research students Peter Morrissey and Nathan Rogers (adviser PI Täuber) have aided us in preliminary numerical investigations.

Given the short award period and its exploratory nature, no publications can as yet be reported.

Technology Transfer

Short-term Innovative Research (STIR) Award:

Toward Control of Universal Scaling in Critical Dynamics

PI: Dr. Uwe C. Täuber, Professor, Department of Physics, 109 Robeson Hall, 850 West Campus Drive, Virginia Tech (MC 0435); phone: (540) 231-8998; email: tauber@vt.edu.

Co-PI: Dr. Michel Pleimling, Professor, Department of Physics, 221 Robeson Hall, 850 West Campus Drive, Virginia Tech (MC 0435); phone: (540) 231-2675; email: pleim@vt.edu.

Co-PI: Dr. Daniel J. Stilwell, Professor, Bradley Department of Electrical and Computer Engineering, 302 Whittemore Hall, 1185 Perry Street, Virginia Tech (MC 0111), Blacksburg, VA 24061; phone: (540) 231-2304; email: stilwell@vt.edu.

U.S. Army Research Office Program: Complex Dynamics and Systems,
Engineering Sciences Directorate, Mechanical Sciences Division.

ARO Technical Point of Contact / Program Manager: Dr. Samuel Stanton;
phone: (919) 549-4225; email: samuel.c.stanton2.civ@mail.mil.

Project duration: May 15, 2015 through February 14, 2015.

Project budget: one month summer salary for each PI (with fringe benefits): total \$ 41,802.

Final Progress Report

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Our in-depth discussions and analysis have resulted in our writing and submitting the research proposal *Control of Universal Scaling, Noise Strength, and Pattern Formation in Critical Dynamics* in response to the *Strategic Program Challenges* call in the *Mechanical Sciences Division* issued by the U.S. Army Research Office. This proposal, which envisions a four-year interdisciplinary research program that will also involve a postdoctoral associated and several graduate students specifically addresses Section 1.3.3, Topic 4: *Control and Creation of Critical Dynamics*, *c.f.* <http://www.arl.army.mil/www/default.cfm?page=206>.

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